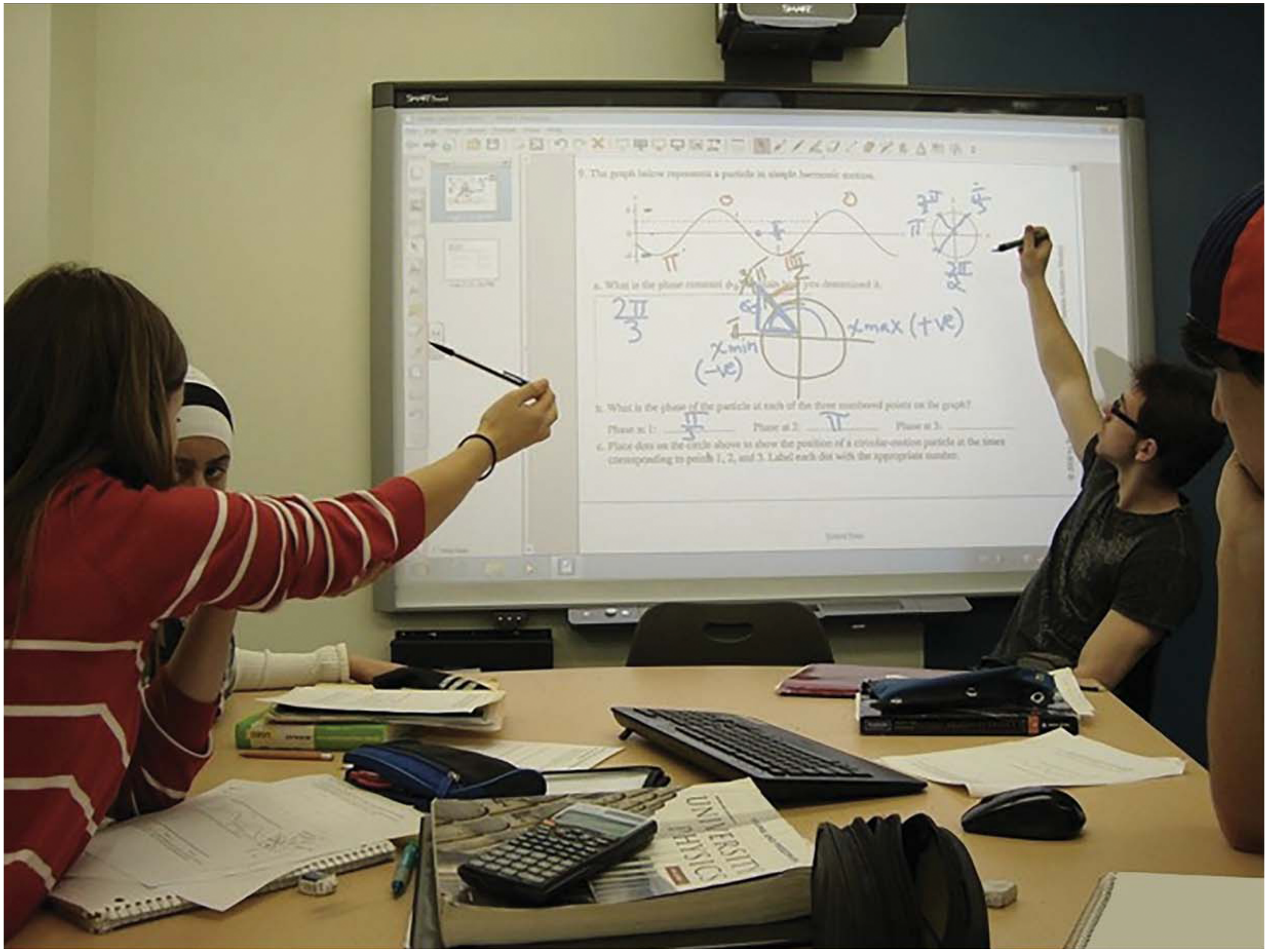
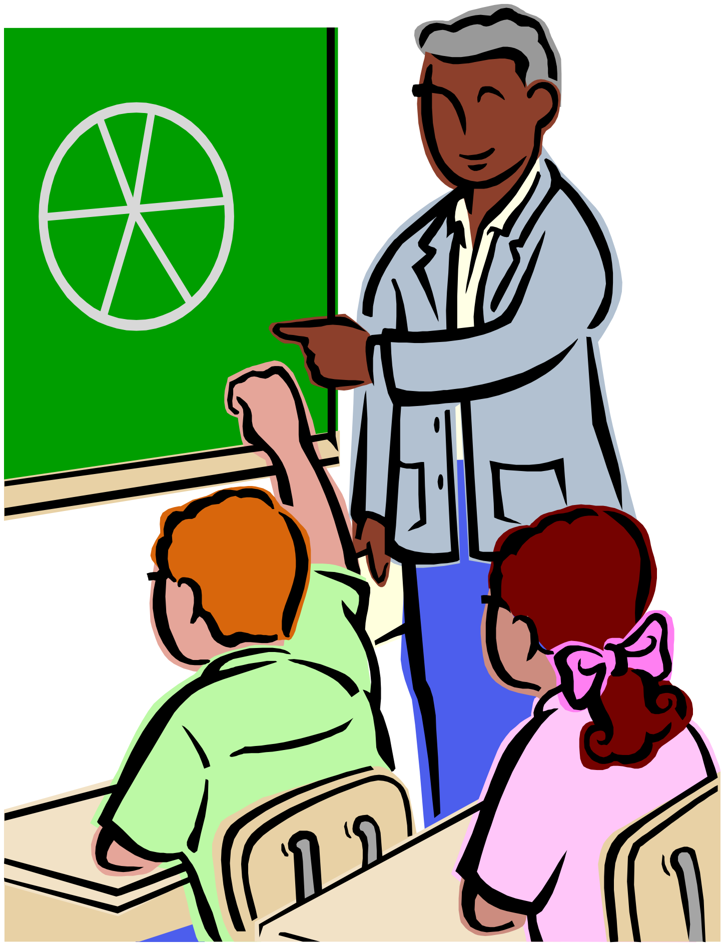
Changing students' approach to learning



How long do you wait for an answer?



Do you ever ask questions in class?

I never answer my own questions in class.

I bring coffee or tea to class in a thermal cup Students think I am addicted to it.

It is a prop. If they don't answer, I sit on the desk and sip.

People don't like silence. If you wait long enough, sooner or later someone will break the silence.

How do we Teach?

How do students learn?

The major problem in teaching is to get students to learn in a **new way**.

They will be resistant to doing this.

They are comfortable with their old ways of learning just as you are comfortable with the way you teach.

Challenges for Students:

Textbooks seem to be written in students' native language and seemingly all that is required is to understand the meaning of the special scientific vocabulary.

This works to the extent of going to France and being taught that chaise is the word for chair, maison is the word for house and so on, but nothing else.

Without grammar, you have great difficulty communicating "where is my hotel; the Louis V?".

For many students in the introductory gateway course, although individual words in the textbook are understandable, the sentences appear to take the form of an unknown language.

A second major problem is that students enter gateway science courses with preconceived beliefs about the nature of science **knowledge and learning**.

Most students have no notion that science could be learned more *effectively* yet in different ways other than how they usually learn it.

If a student believes that knowledge in science should come from a teacher or authority figure, and the class activities require more independent thought than direct intervention, there is cognitive dissonance.

Likewise, if a student comes in thinking that physics consists of a bunch of equations to be memorized, and the instructor focuses more on concepts, there is conflict.

Likewise, if a student comes in thinking that physics consists of a bunch of equations to be memorized, and the instructor focuses more on concepts, there is conflict.

“that’s not how you are supposed to be teaching us”

I want to introduce you to a tool for exploring concepts called *reflective writing*.

I ask all students in every course from the introductory to the graduate level to use this tool to explore concepts in their textbook before they discuss the concepts in class.

REFLECTIVE WRITING

When students arrive in class, they should be prepared to discuss the material that will be presented.

Simply reading the material in the textbook will not work.

They need to actually engage with the material in the textbook, trying to sort out what they understand and what they do not understand.

They should try and relate the concepts to ideas found in previous chapters and to their life experiences.

Instructions

Many of you may have experience that during discussion with others, you can clarify your ideas. Speaking to others is always helpful to obtain a better understanding. The idea of doing reflective writing is to construct a self-dialogue about what you have read. The main diffe
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The main difference between summary and reflective writing is that in a summary you write down what you already have in your mind during your reading, while in doing reflective writing you question what you read and relate it to other concerns.

Instructions

Write down your own understanding of concepts, relationship among those concepts, or even relationship of the material to former chapters and your former knowledge from other disciplines and life experience.

jotting. Write down your own understanding of concepts, relationship among those concepts, or even relationship of the material to former chapters and your former knowledge from other disciplines and life experience.

Don't worry if what you are writing is right or not. Marking is not based on that.

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Marking criteria for reflective writing

Features present in the reflective-writing product	Meets criteria fully (100%)	Meets most of the criteria (65%)	Minimally meets the criterion (35%)	Does not meet criterion at all (0%)
Presenting the key concepts of the subject as understood by the student.	Complete -Does not copy the lesson.	Covers all concepts but not really in own words	Partial coverage of concepts	
Describing the relationship between the various concepts	-Qualitative interpretation used to compose the relationship in the words of the student. -	-Surface description of Qualitative interpretation used to compose the relationship . -	-Some attempt to compose the relationship .	Not able to interpret.
Student relates key concepts to his/her own life experiences	Shows clear understanding of how the concepts occur in everyday situations	Shows partial understanding of how the concepts occur in everyday situations	Mention of everyday situations without any explanation of how they relate to concepts under study in current sections	No relationships to his/her own life experiences are given.
Student formulates his/her own question(s).	Student realizes that there are concepts in the textbook that s/he does not understand and elaborates a clear question	Student sets out a question that is not clearly formulated	Student notes the difference between the students' own ideas and the versions found in the textbooks without any discussion	No questions given

There are other methods to get students to read assigned material before classes;

- having students take quizzes on the chapter in class
- having students summarize the material in the chapter and hand in the summary each week.

However, neither of these methods helps students to engage with the material before attending class.

The traditional lecture

Many years ago I attended a workshop given by Graham Gibbs, a noted expert on study skills.

- Gibbs had been asked by a noted historian to help his class with note taking.
- He was to observe the class and during the last 5 minutes of class speak about note taking.
- The professor spoke about voyages from Europe to North America.
- The professor was an engaging speaker.
- Graham Gibbs forgot why he was at the class.
- He seemed to even smell the salt water carried by the wind.

- Suddenly he remembered why he was there and looked around the class.
- Surprisingly, at even the most interesting parts, students were staring out the window!
- Graham Gibbs tore up his notes.
- He handed the professor a transparency.
- He asked the professor:

  "Write down the three most important points that you wanted students to take away from this class"
- He asked the students:

  "write down the three most important points that they had derived from the class."

The professor displayed the transparency

Gibbs asked how many students had written down all of the points that the professor had written on the transparency.

How many students raised their hand?

Not a single student raised a hand.

Gibbs then asked how many students had written down two of the points that the professor considered to be the most important points that students should have derived from the class .

Not a single student raised their hand.

When students were asked if they had written down one of the three points that the professor wanted them to take away from the class, a few students near the front timidly raised a hand.

I should make clear at the outset that I am not opposed to lecturing –
In all but one of my courses, I do it all the time.

Rather, it is necessary to supplement lectures with other activities

conceptual-conflict collaborative group exercises

(Kalman, Morris, Cottin and Gordon 1999)

Students are presented with a Conceptual problem

While the groups are working on the problem posed on the slide, the professor walks around and notes groups that come to different conclusions.

Representative groups with different conclusions are invited to come forward and present their conclusions.

The spokespersons of each group then debate the issue between themselves and then the rest of the students are invited to address questions to this panel of “experts”.

To underline that there are two concepts in conflict, the two opposing issues presented by the two groups are clearly stated and the class then votes on which concept resolves the demonstration or qualitative problem.

This voting is essential because students who have compartmentalized concepts often misinterpret statements made by instructors.

Then the professor resolves the conflict by explaining with the aid of experiments how the replacement concept describes the demonstration or qualitative problem is in accord with experimental findings, while the personal (alternative) scientific conception fails to do so.

Comparison of the Effectiveness of Collaborative Groups and ***Peer Instruction*** in a Large Introductory Physics Course for Science Majors

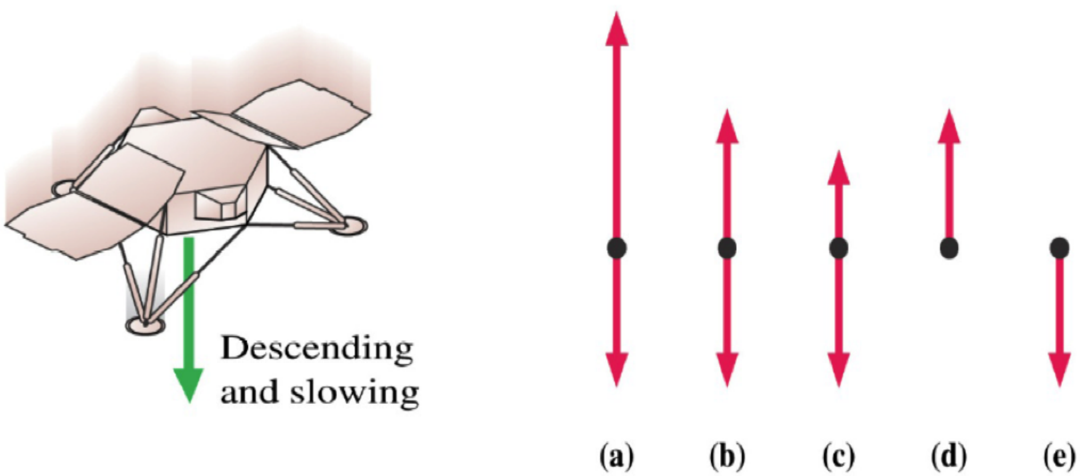
Calvin S. Kalman, Marina Milner-Bolotin, and Tetyana Antimirova

Canadian Journal of Physics 88, (5), 325-332, 2010.

Two equally experienced instructors (two of the paper authors) T & M were teaching an introductory first year physics course for science majors in a large public university in Toronto. Students were randomly assigned to the two sections of the course taught by T (N=110) & M (N=148).

The first question on the FCI and questions 5, 11 and 13 on the final exam were used to compare the interventions.

5.* A Martian lander is approaching the surface. It is slowing its descent by firing a rocket motor. Which is the correct Free-Body-Diagram for the lander?



11. A plane is flying horizontally at a constant velocity. A 30 kg package is dropped from this plane. Provided air resistance is negligible, an observer on this plane will see the package:

a) quickly lagging behind the plane while moving down.
b) falling down while remaining under the plane.
c) moving at constant horizontal velocity in the plane's direction
e) none of the above

13. A person stands on the edge of a cliff. She throws three identical rocks with the same speed. Rock U is thrown vertically upward, rock D is thrown vertically downward, and rock H is thrown horizontally. Assuming the ground at the base of the cliff is flat, which rock hits the ground with the highest speed? Explain.

a) Rock U
b) Rock D
c) Rock H
c) Rocks U and D
e) They all hit the ground with the same speed.

Modified Peer Instruction

A clicker question is posed

Students work individually for about a minute to figure out the answer that they submit using clickers

Students' responses are displayed to the class without revealing the correct answer

Many of the students answered incorrectly.

Students work in groups of 2-3 to discuss the question.

Students resubmit individual answers using clickers.

Most of the students provided a correct response. Correct answer revealed.

An instructor leads a summary discussion with the class: the reasons for correct answer as well as the reasons for choosing the incorrect answers are elicited from the students.

Students work in small groups (of 2-3) to figure out conceptual questions

Final Exam Question	Score section T	Score section M	Activity type Section T	Activity type Section M
Final Q13	64.10%±5.5%	55.08%±4.6%	CG (T)	PI (M)
Final Q11	46.15%±5.7%	49.15%±4.6%	PI (T)	CG (M)
Final Q5	71.79%±5.1%	56.42%±4.5%	CG (M)	PI (T)

Only the students who wrote all the assessments were included in the data analysis:

For Section T: 54 students
For Section M: 77 students

For Question 5 the Collaborative group method produced a statistically significant higher score ($p=0.017$).

For Question 13, the class that used the Collaborative group method produced a higher score with virtually no overlap within the statistical error.

For Question 11 there is no statistically significant difference between the methods, even though the CG method produces a higher result for this question.

Overall the Conceptual Conflict Collaborative Group method seems to be more effective than the Modified Peer Instruction method.

In this experiment, it was necessary not only to alternate the concepts, but also to eliminate the effect of different professors in the two classes.

Table 1: Interventions in two sections (T and M) of the introductory calculus-based mechanics course. Each section is exposed to both the conceptual conflict collaborative group method (CG) and modified peer instruction method (MPI).

Concept \ Instructor	T	M
A. Vertical 1-D motion with constant acceleration: objects thrown from the edge of a cliff.	CG (T)	MPI (M)
B. Inertia & graphical representation of motion: sandbag dropped from ascending balloon	MPI (T)	CG (M)
C. Newton's second Law: Forces on a body in a moving elevator	CG (M)	MPI (T)
D. Free fall versus motion in the presence of air resistance: Vertical motion of bodies dropped from a high tower	MPI (M)	CG(T)

Hewson and Hewson (1984) suggest that if a student holds a personal scientific concept, he or she does so because the student finds it to be *plausible*.

Suppose that you present a concept that differs with this personal scientific concept.

No matter how clearly you present the concept, will the student accept what you say?

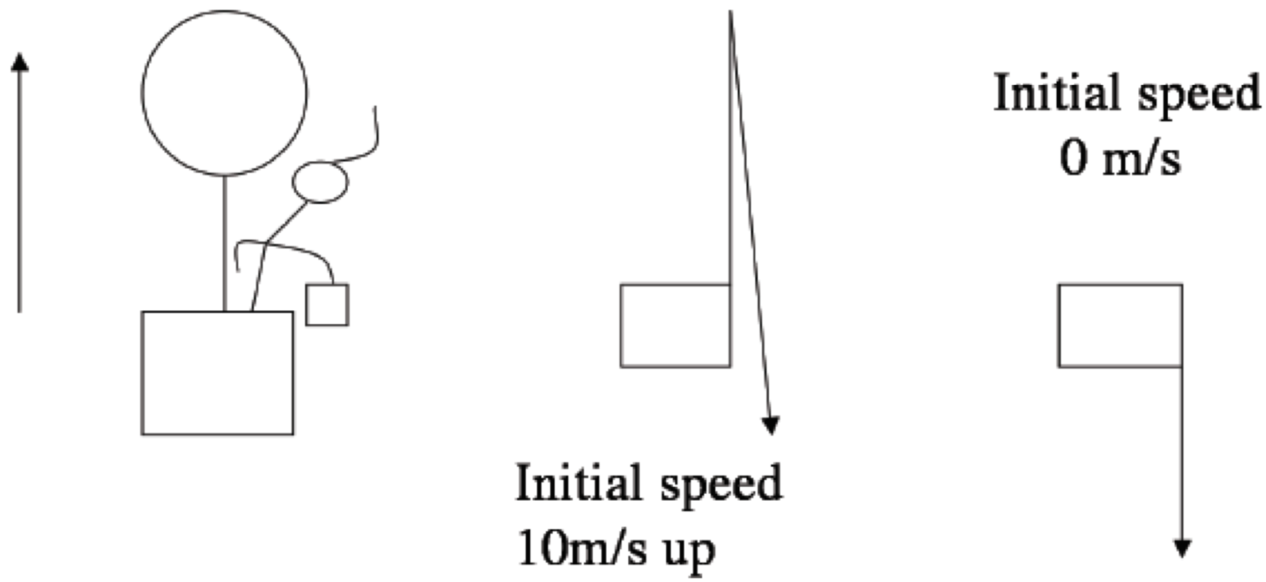
Instruction must first seek to reduce the plausibility of the student's personal scientific concept.

Feyerabend has pointed out evaluation of a theoretical framework doesn't occur until there is an alternative.

Kalman, C. S., Rohar, S. & Wells, D. (2004) introduced an additional activity—a written *critique*—*to* examine alternative possibilities critically.

In my course, the critique exercises are worth 5% of the course mark.

The critiques are designed to cause students to undergo a "*critical discussion to decide* which natural interpretations can be kept and which must be replaced" (Feyerabend, 1993, p. 59).



At the left we see a sandbag being dropped from a balloon . (Give as many reasons as possible for each viewpoint.)

Critique#2–Suggested length 2 pages, but there is no page limit.

In the critiques, students are required to present arguments in favor of both their personal scientific concepts and the scientific explanation described by the instructor, with the aid of supporting experiments at the end of the conceptual conflict collaborative group activity.

They must also clearly indicate which position is verified by experimental evidence (with references to the evidence.)

Based on these position statements, I find that at most 5% of students still insist that their personal scientific concept is correct.

These students are asked to see me.

We have developed a number of activities to engage students in learning:

Reflective Writing Tool (Kalman, Aulls, Rohar, & Godley 2008),
conceptual-conflict collaborative group exercises (Kalman, Morris, Cottin and Gordon 1999; Kalman, Milner-Bolotin, & Antimirova (2009))
critique writing exercises (Kalman, Shelley Rohar and David Wells , 2004)
Course Dossier Method (Kalman, 1996)
Examining history of physics from viewpoint of different philosophers of science (Kalman, 2010)
Physics Labatorials (Thomson, Sobhanzadeh, Kalman, 2015)

Table I. Some of the Studies Comprising Program of Research.

Study	Setting, Population	Method	Purpose
Study 1 (1999) Kalman, Morris, Cottin, & Gordon	University, 2 groups of students in two successive years	-Quantitative	Explore the collaborative-group exercise as a stand-alone activity
Study 2 (2004) Kalman, Rohar, & Wells	University, 2 more groups of students in two successive years	-Quantitative -Students taught by a different instructor than in Study 1 **Year 1**: as in Study 1, collaborative group utilized without follow-up of critique exercise **Year 2**, Collaborative- group exercise followed up by critique exercise	Modifications were made to the interventions explored in Study 1: Conceptual conflict model (using collaborative group exercises) enhanced by the introduction of the writing-to-learn exercise (“critique”)
Study 3 (2008) Kalman, Aulls, Rohar, & Godley	University sample of students from Study 2, year 2	-Qualitative	Analyze reflective writing as a stand-alone activity
Study 4 (2010) Milner-Bolotin, Antimirova, & Kalman	University, 2 groups of students in a single semester	-Quantitative	Comparison of the conceptual conflict collaborative group method with peer instruction
Study 5 (2010) Kalman & Rohar	University, 2 Colleges. - 3 groups of students in a single semester	-Qualitative	Comparison of students from University and one College performing the reflective-writing activity, collaborative-group exercise and critique exercise. Comparison with the second College was for the reflective-writing activity only.

Study 6 (2010) Kalman	University	Essay question at beginning & end of course, student writing products	Explore if students' views on the Nature of Science can be changed in studying philosophers of science.
Study 7 (2011) Lee, Ha, & Kalman	University	Analyzing group discussions and written student responses	Analysis of a lesson from a hermeneutic perspective
Study 8 (2012) Huang & Kalman	University and College. 2 groups of students in a single semester	Quantitative scores on a survey; interview transcripts and students' writing products	Explore if reflective writing enables students to approach science textbooks in the manner of a hermeneutic circle
Study 9 (2014) Kalman, Milner-Bolotin, Shore, Aulls, Charles, Lee, Antimirova, Coban, Lopes Coelho, Kaur Magon, Huang, Ibrahim, & Wang	University and College 4 groups of students in a single semester. [2 groups at each institution]	- Rubrics on writing products plus qualitative analysis of the pre- and post-interviews	Explore a suite of activities can change the way students learn and exceed the outcomes of stand-alone studies

Study 10 (2014-15) Sobhanzadeh Kalman & Thompson	University. two courses over two semester	interview transcripts and students' writing products and epistemological test	Explore how students do reflective writing and if the combination of of reflective-writing activity, and labatorials can change the way students learn
Study 11 (2014) Khanam & Kalman	University humanities students in one course & physics students in an advanced course	interview transcripts and students' writing products	Analysis of the course dossier method to see if it can help students understand physics concepts and humanities students change their understanding of the nature of science

Study 8 (2014)
Kalman, Milner-Bolotin, Shore, Aulls, Charles, Lee, Antimirova, Coban, Lopes Coelho, Kaur Magon, Huang, Ibrahim, & Wang

Study Objectives:

We attempt to bring students to recognize that mechanics can be viewed as a coherent "framework".

A coherent framework is a highly ordered knowledge structure that embraces concepts, methods of applying concepts to solve problems, etc. It contains a coherent set of interrelated big ideas.

As students learn, they relate new material to the material that they feel they already understand and in the process accommodate the new material within the framework.

We do not attempt to determine if any single activity is more effective than lectures or more effective than another kind of activity.

The purpose of this study was to investigate if and how the **combined** implementation of reflective-writing activities, critique-writing activities, and reflective write-pair-share combined with conceptual-conflict collaborative-group exercises **could change students' approach to learning physics over and above the impact of each approach undertaken alone, and also enhance their learning**.

Specifically the first objective is to help students to recognize the importance of concepts in learning physics.

The second objective is to get students to change their learning approach to situate concepts within a framework.

Thirdly, to get them to review all their concepts and ask how they fit into the framework presented in the textbook and by their instructor.

This investigation was conducted at two different institutions over a three-year period. At Institution A, a comprehensive university, classes were relatively large sections (over 100 students each) of a typical calculus-based course in mechanics. At Institution B, a community college, there were relatively small classes (about 32 students each) of a typical algebra-based introductory course in mechanics, electricity, and magnetism.

The two institutions used different textbooks and had different formats.
All sections considered in this experiment at each institution were taught by the same instructor who was not part of the research team that authored this paper.

The first year of the project (spring 2009-fall 2010) was devoted to development of Rubrics to examine reflective writing, critiques and interviews that utilizing courses in the fall 2010 semester.

Inter-rater reliability for the rubrics was tested with actual data before the final coding of responses began. Every available written submission from the students in winter and spring 2011 was circulated to the authors so that each writing product was evaluated by two or three different evaluators

We collected data during spring 2011 through winter 2012. Altogether, two sections in spring 2011 and two sections in fall 2011 were utilized at institution B a total of 120 students.

A further two sections in winter 2011 and one section in winter 2012 comprising 200 students were utilized in institution A.

In institution B in fall 2011 one section (experimental groups) was exposed to all three of the target activities. The other section (control group) was asked to submit only summary writing of textual material before coming to class.

Results:

The experimental group the students in the group had significantly lower initial FCI scores with a relatively strong effect size than those in the summary-writing (comparison) group, $F(1,48) = 26.01$, $p < .0001$, $\eta^2 = .35$.

The unadjusted **mean of the experimental group on the final exam score was 42.47, and that of the summary-writing group was 36.35, differing by 6.12**.

This difference was significant, $F(3, 48) = 9.04$, $p < 0.0001$, and the effect size, $\eta^2 = .36$, was relatively strong.

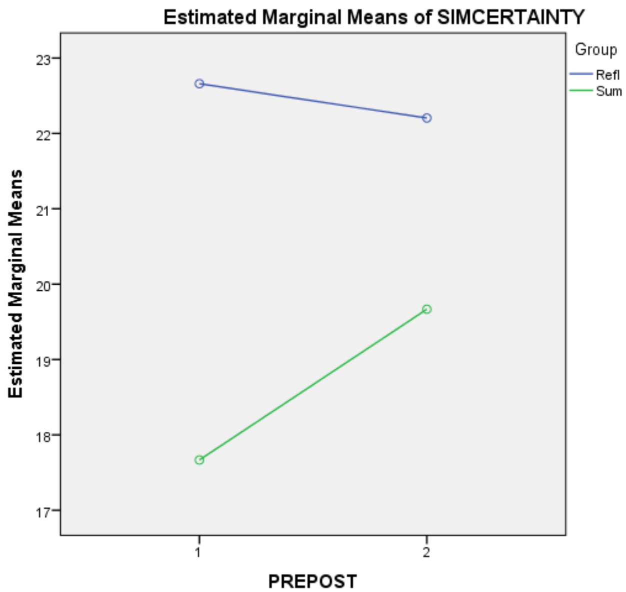
The experimental group appeared to overcome their initial disadvantage reflected in the FCI scores and surpassed the comparison group in actual course performance as well as in their thinking processes as shown in the qualitative (interview) data.

Was there epistemic change in students in the experimental group and control group after taking the course for one semester

Before and after the intervention, the participants of both groups were asked to fill out the *Discipline-focused Epistemological Beliefs Questionnaire* (Hofer, 2000) adapted for the domain of physics.

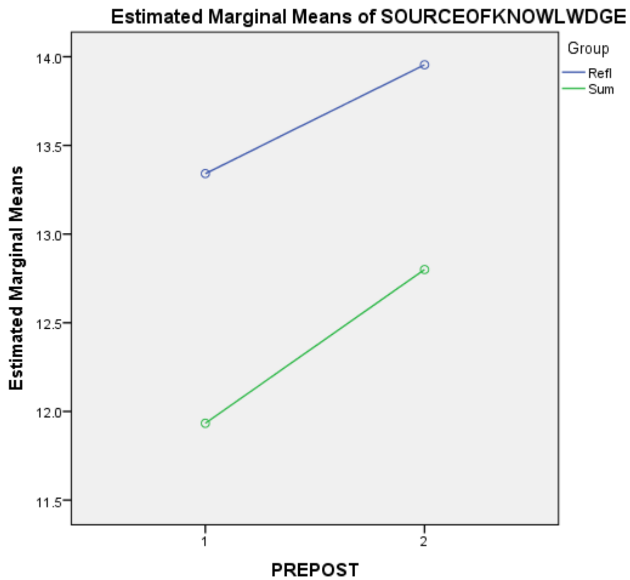
We could only use data for those students who actually chose to fill out the questionnaire adapted for the domain of physics (DFEBQ) at the beginning and end of the course from the experimental group (n = 44) and control group (n = 15).

In the DFEBQ, the four epistemic belief dimensions are Certainty/Simplicity, Justification of Beliefs, Source of Knowledge, and Attainability of Truth

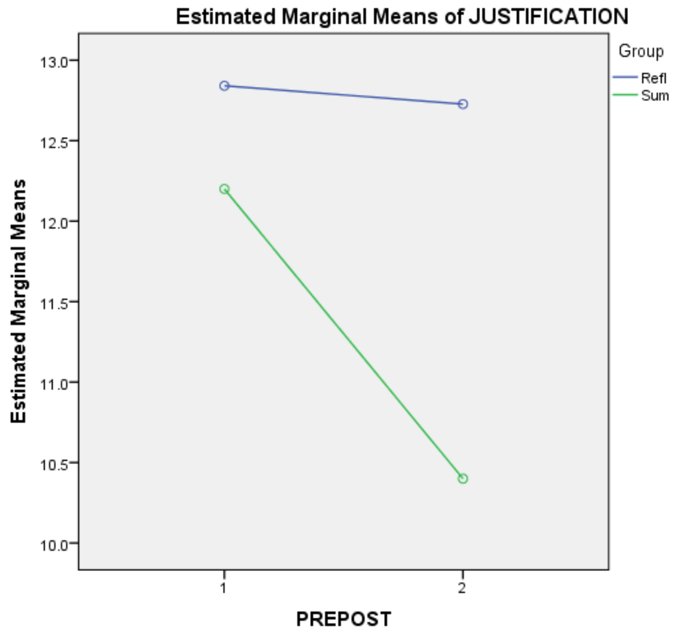


in the dimension Simplicity/Certainty, the reflective-writing group developed their epistemic beliefs toward a more advanced level, whereas the summary-writing group showed the opposite trend.

This was in the direction of what we expected, although the change was not significant. If true, that means students from the reflective-writing group, given time, came to believe that knowledge is complex and evolving instead of being simple and fixed.

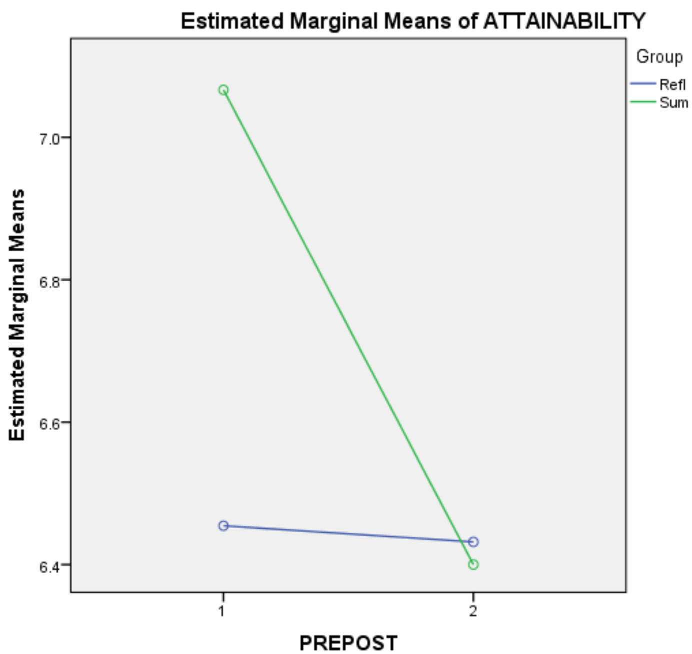


In the dimension of Source of Knowledge, both groups tended to believe that knowledge is handed down by authorities more and more, which means their beliefs did not develop but became less sophisticated.



In, both groups' epistemic beliefs become less advanced, with the summary-writing group experiencing a bigger setback than the reflective-writing group.

Justification of Knowledge refers to the knower's evaluation or estimation of their knowledge in relation to the authority's knowledge. The difference between the size of the changes was significant.



In Attainability of Truth both groups had growth in their beliefs, with the summary group having a bigger change than the reflective group, which means both groups saw knowledge as more attainable.

Although this change was not significant, it was in the direction we expected.

At both institutions some students exhibited changes in how they viewed learning. Students categorized this as “Seeing concepts from different perspectives” (five students) and “Seeing physics (or other knowledge) as more than a collection of facts, having a relational structure” (five students).

“Have you changed the way you learn as a result of taking this course?”.
Four out of five students in institution A and at least three out of eight students in institution B responded positively:

The ways in which this occurred differed from student to student, but all of these students reported “less reliance on the textbook.”

“Why do you think the professor has given you this activity, reflective writing?”:
four of five students in institution A responded “identifying important ideas”
four “Thinking about what you are learning.”
Three “Integrating ideas”
Three “recognition that disagreements can be good.”
Five of eight in institution B reported “identifying important ideas” Three “Thinking about what you are learning”.

Overall, this study had potential access to data 346 students.

34 critiques made available for students in winter 2011 and spring 2011. Nine of these products were from six experimental-group students at Institution A, and 25 critiques were written by 25 students at Institution B. Forty-three more critiques from a further 11 students in institution A in winter 2012.

Institution B: by a wide margin, the largest number of responses, 52 of 129, were scored as the maximum 3. The mean rating was 2.14.

Institution A: similar but less positively skewed.

Students who engaged in critique-writing activities acquired the skill to write critiques that reflected ability to identify key concepts and other target performance of the present study.

Reflective-writing activity

We analyzed 249 reflective-writing products for winter 2012 and fall 2012 students

Typical results

Table VIII. Institution A Winter 2012.

Ratings of the Writing Products (Maximum Possible = 3)

	Fluent, students' own words	Identifies concepts, own words	Relates concepts to previously studied concepts	Relates concepts to life experiences	Identifies conflicts with own ideas
Student 17 Ch4(1-3)	1.3	1	1.3	0.3	0.3
Student 17 Ch4(4-6)	3	3	2.7	2.3	1
Student 17 Ch5	2.3	2	2.3	2.3	1
Student 17 Ch6	2.3	3	3	3	0.3
Student 17 Ch7	3	3	2.7	2.7	1.3
Student 17 Ch8	2.7	2.3	2.3	2.3	3
Student 17 ch11-12	1	1.7	1	2	0.7
Student 19 Ch4(4-6)	3	2.3	0.3	0	0.3
Student 19 Ch5	3	3	3	3	0
Student 19 Ch6	3	3	3	3	2
Student 19 Ch7	2.7	2.7	1	3	0
Student 19 Ch8	1.3	1.3	0.3	3	0
Student 19 ch11-12	3	3	0	3	0

Interviews

Students were asked what they had done at the beginning, middle and end of the course to learn physics.

Students doing summary writing reported that that they were doing the same activities at all three times; typically- reading the textbook, summary writing and attending the tutorial session.

In the reflective writing group a typical student reported that at the beginning of the course he was looking for direct examples of how to solve the particular problem.

By the middle of the course, he was trying to think of the points he needed to take out of the chapters and write notes about them.

More details emerged that students had actually changed their ways of learning.

One student stated: “I don’t know if I’m older or anything but now I don’t just want to copy and paste equation but to actually understand.”

He was now more systematic: “Not just memorizing it; actually understanding. To actually apply it and to know how it actually works.”

Another said “I kind of noticed that I am being forced to maybe change the way I think about things

“The course has developed new ideas and ways of seeing things.”

Study 10 (2014-15) Sobhanzadeh Kalman & Thompson

The name “labatorial” comes from a combination of “laboratory” and “tutorial”.

Students use a worksheet with conceptual questions, calculation problems, and instructions for the experiment and computer simulations

Labatorials highlight the physics concepts covered in lectures and encourage students to present and share their ideas with one another

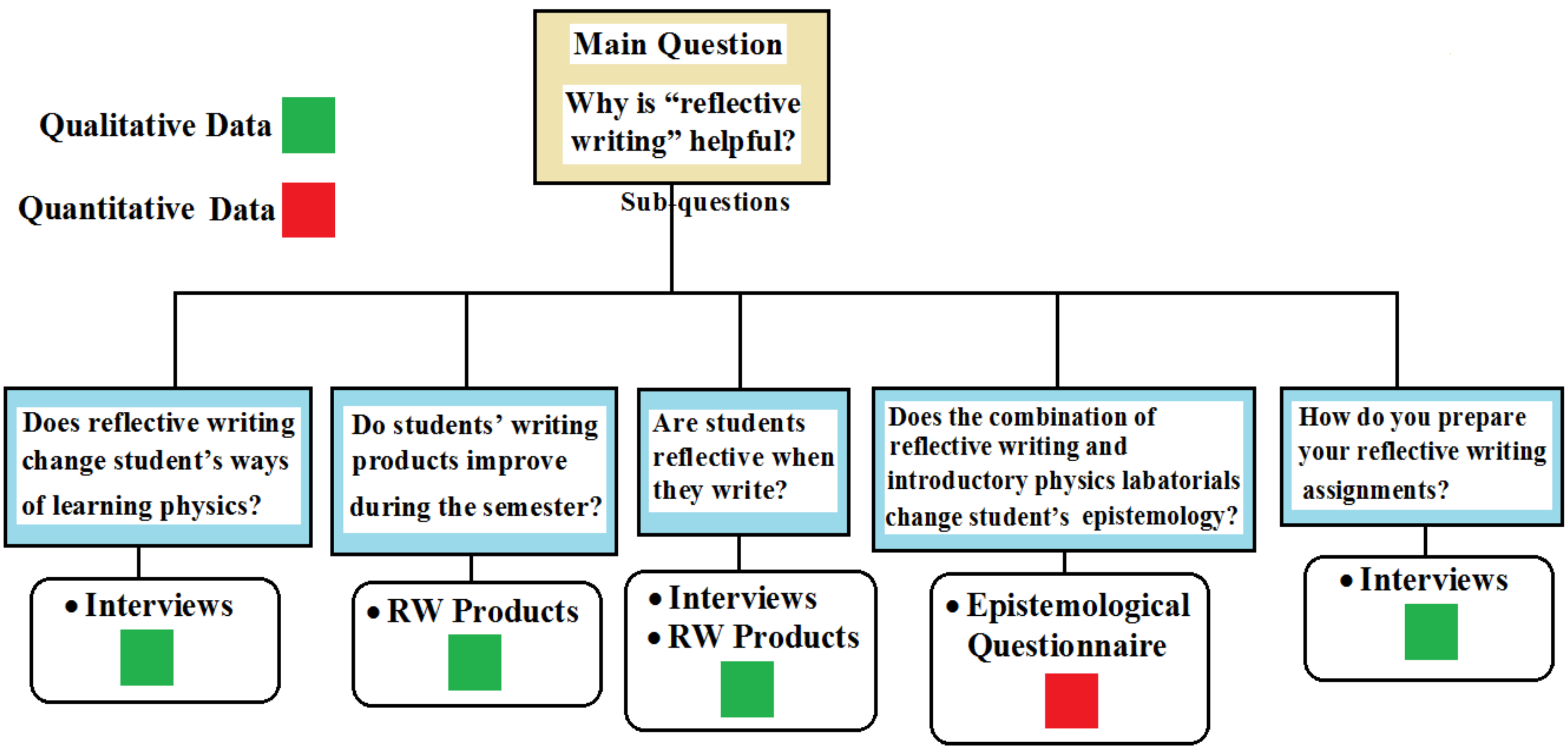
Each labatorial worksheet starts with conceptual questions and then asks students to make predictions. After doing the experimental part, students need to explain whether their results support their prediction or not

In labatorials, students complete a labatorial worksheet in groups of 3 or 4 students.

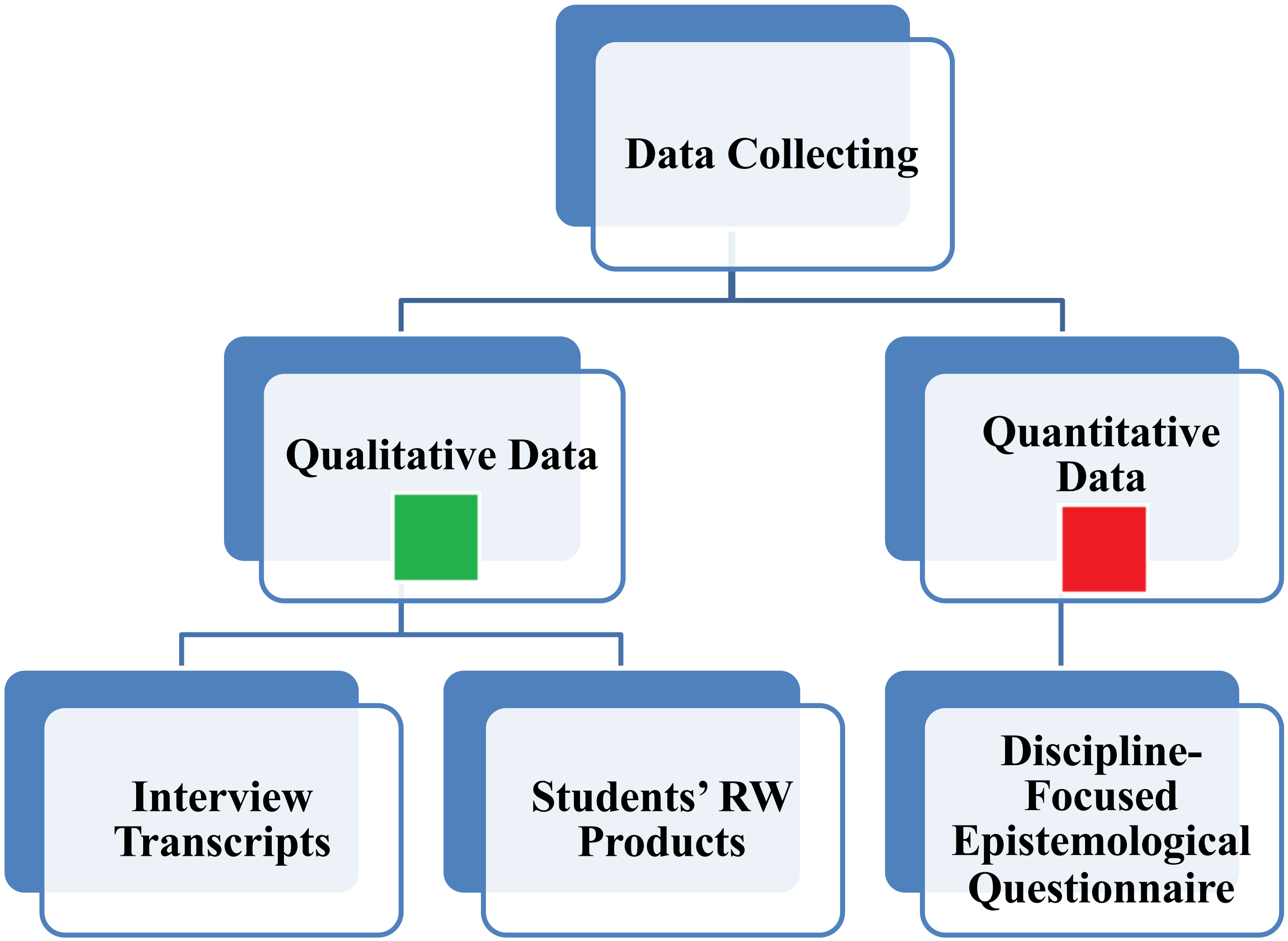
There are usually 3 to 6 checkpoints in each labatorial. Each time the students reach a checkpoint, they review the answers with the lab instructor.

If the answer to a question is wrong or students are not proceeding in the right direction, the lab instructor leads the students to find the correct answer by themselves, exploring and discussing alternative ideas.

Research Questions



Data Collecting and Analysis

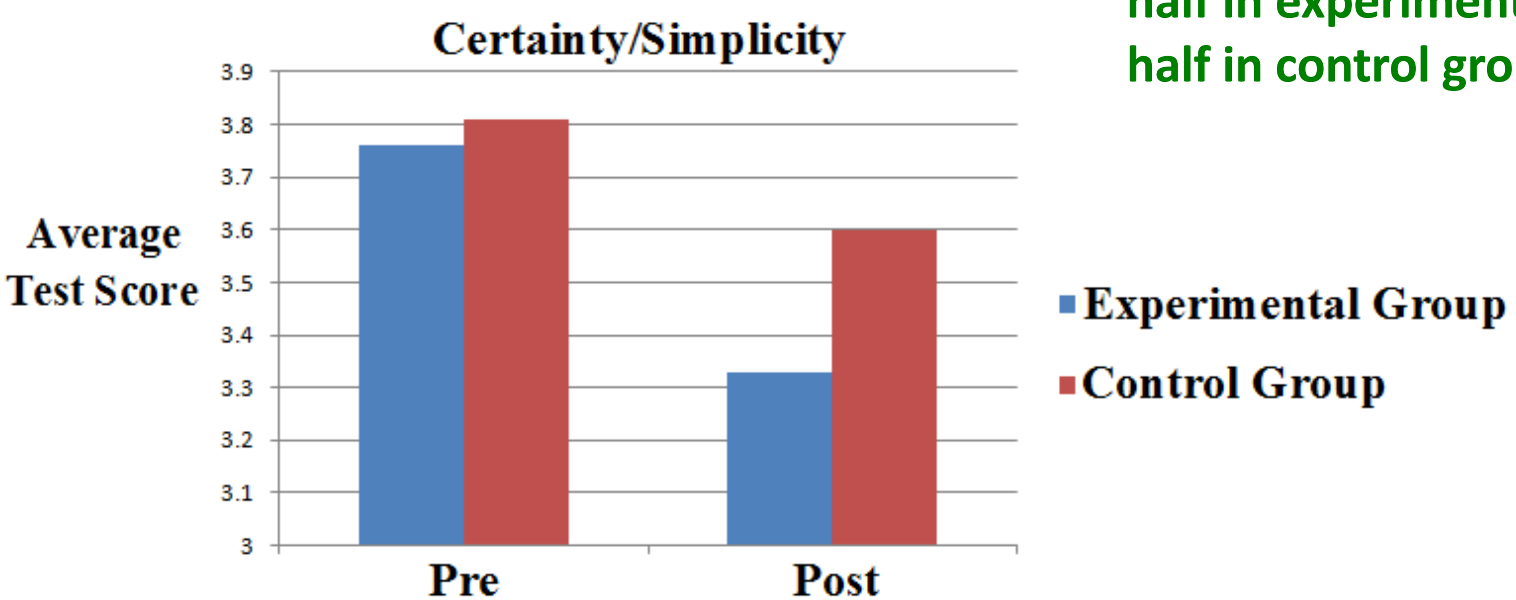


Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, *25*(4), 378-405.

Epistemological results

Certainty/Simplicity:

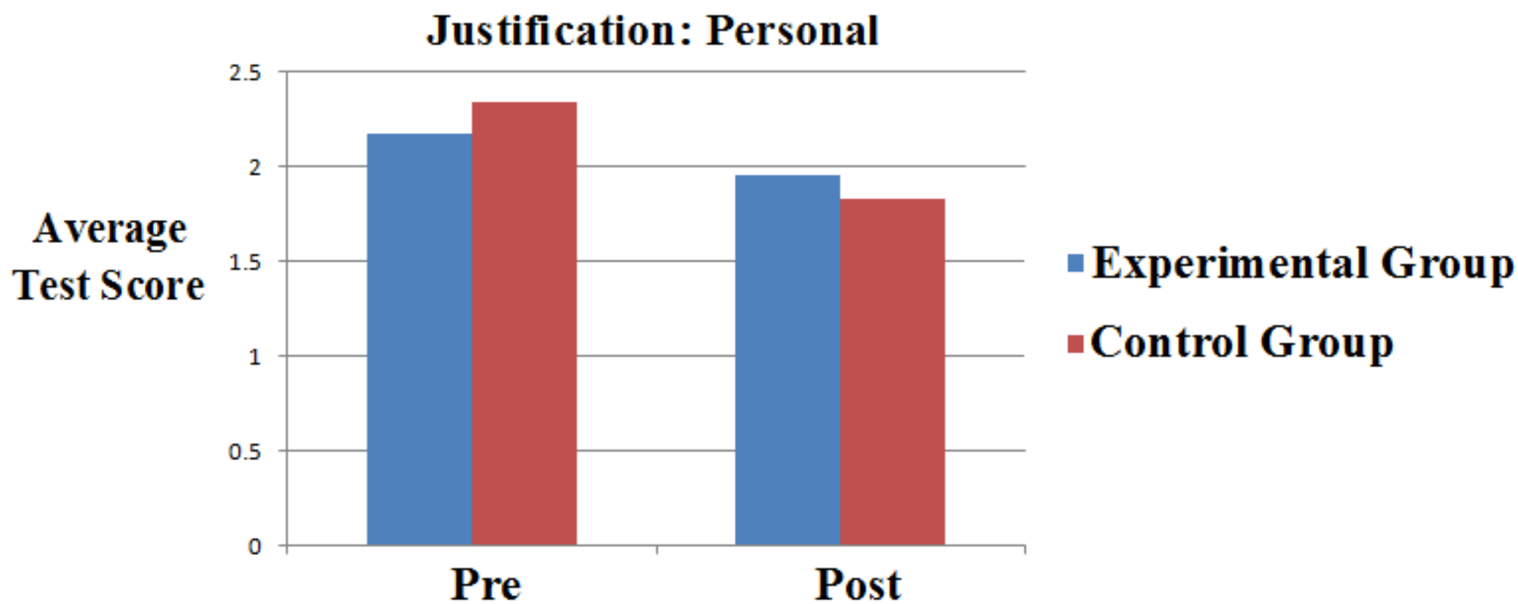
About 200 students
half in experimental group
half in control group



- There is an epistemological change in both control and experimental groups
- Change between experimental and control groups is significant

Epistemological results

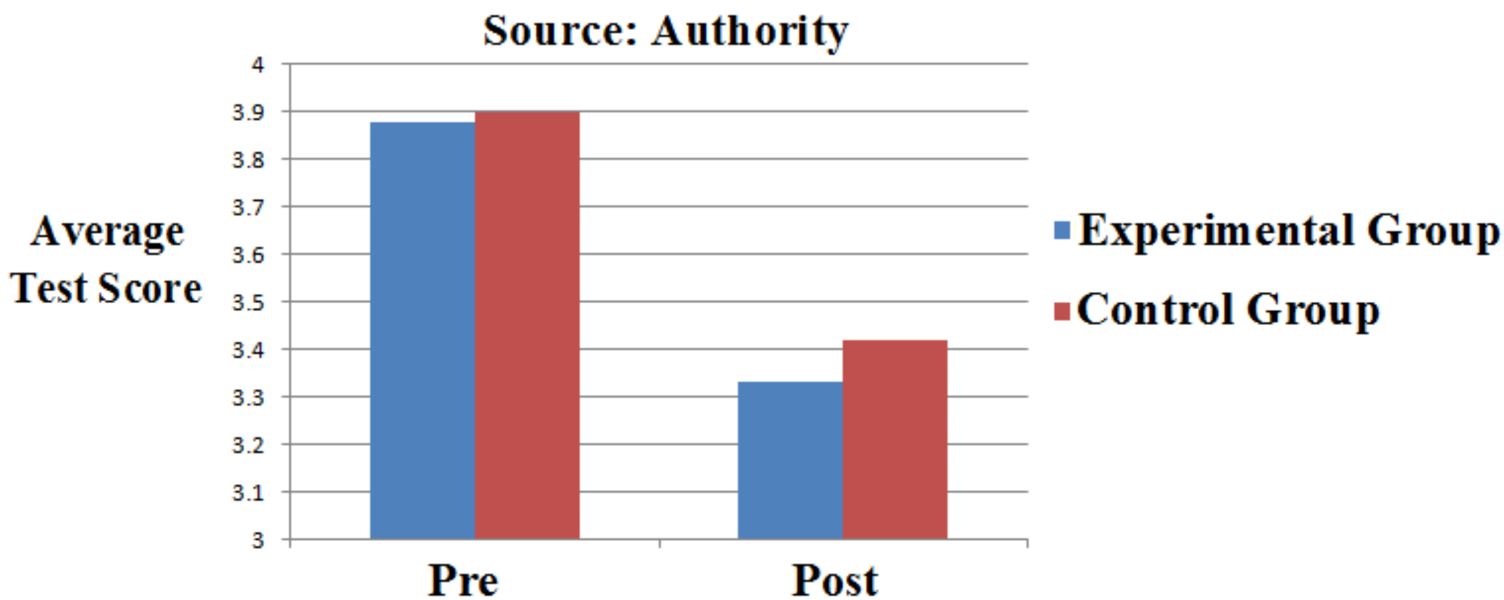
Justification: personal



- There is an epistemological change in opposite direction
- Change between experimental and control groups is significant

Epistemological results

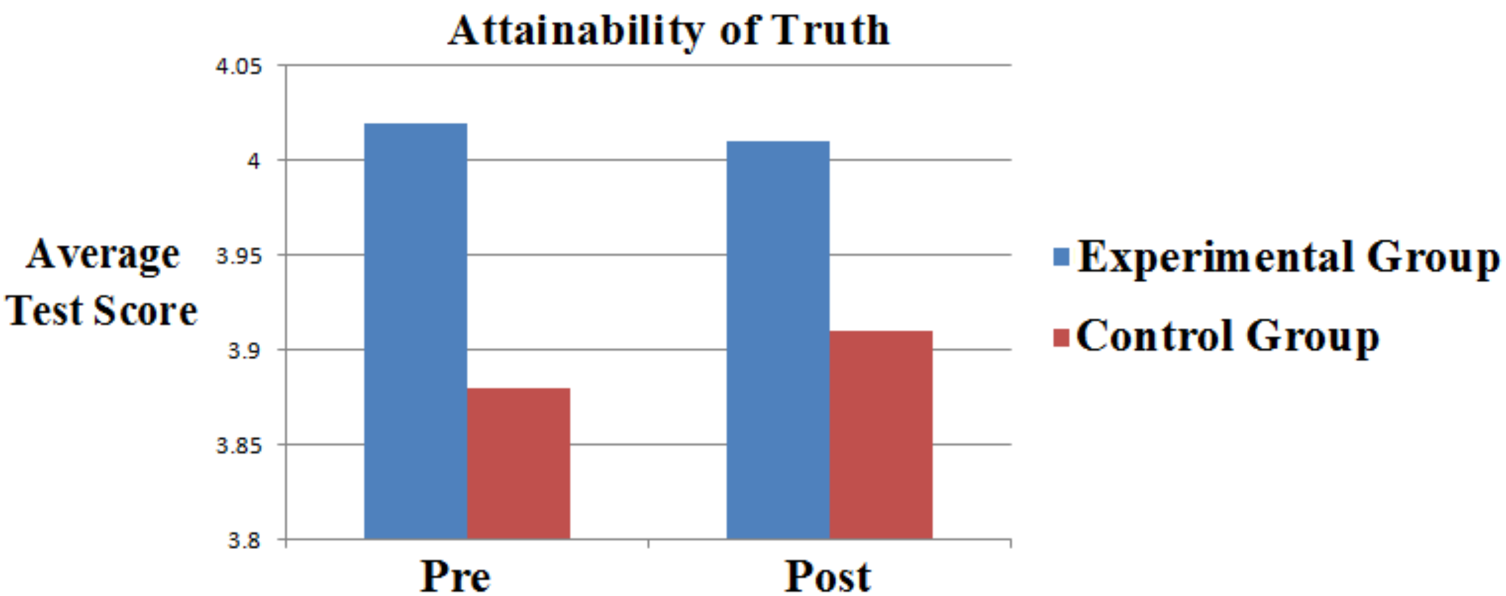
Source: Authority



- There is an epistemological change in both control and experimental groups
- Change between experimental and control group is not significant

Epistemological results

Attainability of truth



- There is no epistemological change in both control and experimental groups

Conclusions:

The main results of these studies were the changes in students' approaches to learning physics, especially as revealed in the interviews. Final examination results were a bonus.

Although traditional problem-solving was not specifically targeted by the experimental course activities, it improved.

Because the students in the experimental group had come to think of the course in terms of a framework, they most likely had developed a paradigm approach to solving problems rather than relying on treating each problem type as a domain of its own (with a plug-in formula). This could explain their higher achievements on the end-of-course examination.

Conclusions:

Administration of the *Discipline-Focused Epistemological Beliefs Questionnaire* showed that the novice science learners become more expert-like and saw knowledge as interconnected

Analysis of the results based on the rubrics showed that that the students in the experimental group were able to identify concepts and relate them to previously studied concepts within the course and to their own life experiences.

They came to the realization that some ideas/facts/data presented in the textbook are in conflict with the students' own ideas.

Most of them were also successful in discussing the conflict.

In doing the critiques, faced with scenarios taken from two different frameworks, all but one of the students were able to justify the point of view of their framework.

Conclusions:

In the interviews, students typically stated that they were "thinking about some of the concepts we are taught for problem solving."

students stated that they viewed learning as "Seeing concepts from different perspectives" (five students) and "Seeing physics (or other knowledge) as more than a collection of facts, having a relational structure" (five students)

Implications for Physics Teaching

Implementing the pedagogical strategies has the potential to help instructors in introductory physics courses to empower their students in learning science by learning how to learn.

It can help them perform better. Moreover success in courses resulting from acquiring such strategies can help retain students beyond gateway courses in science.

It is important to use a combination of activities--the suite is more effective than any of the single activities on its own--and to make participation compulsory. The activities should be built into the evaluation system

Thanks!!